Oct. 19, 1965 M. E. RINGENBACH 3,213,454
FREQUENCY SCANNED ANTENNA ARRAY
Filed March 21, 1960 4 Sheets-Sheet 1

FIG. 1

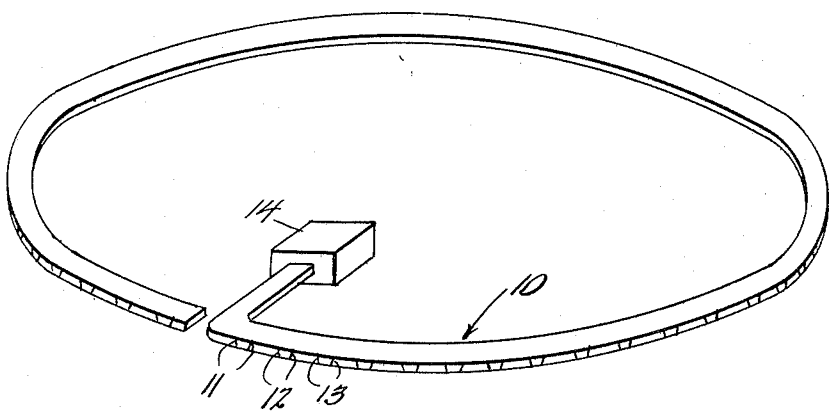


FIG. 2

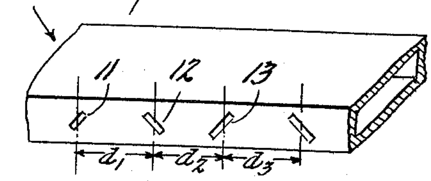


FIG. 3

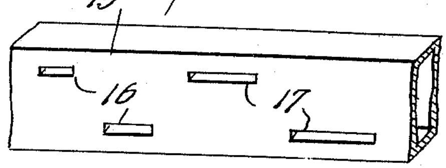
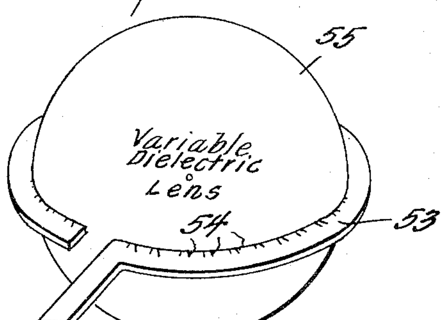


FIG. 6



INVENTOR
Maurice E. Ringenbach,
BY Alfred B. Levine
Seymour M. Rosenberg
Robert H. Lentz
ATTORNEYS

FIG-4-

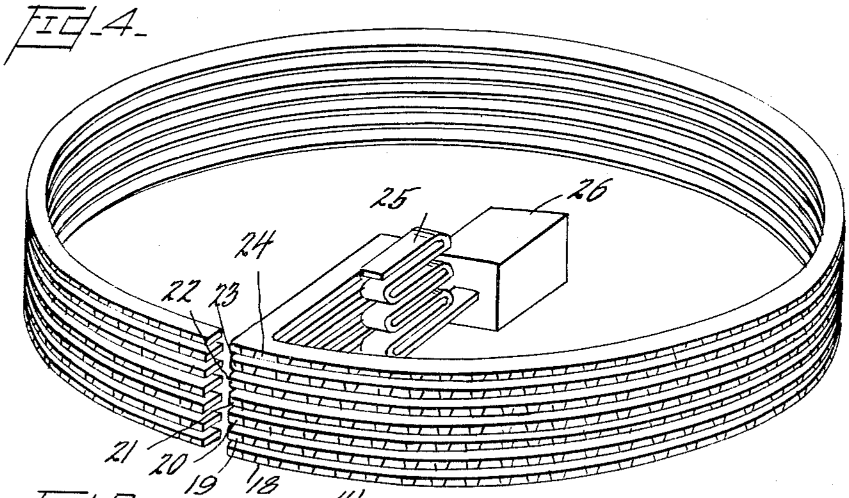


FIG-5-

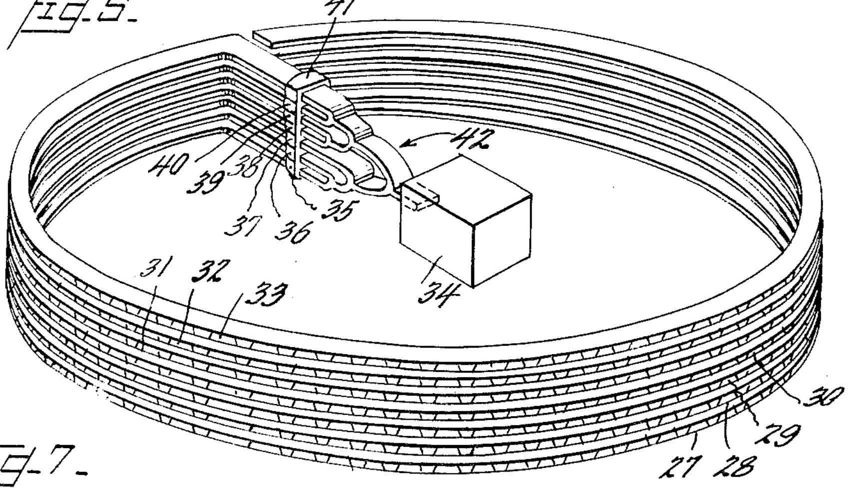
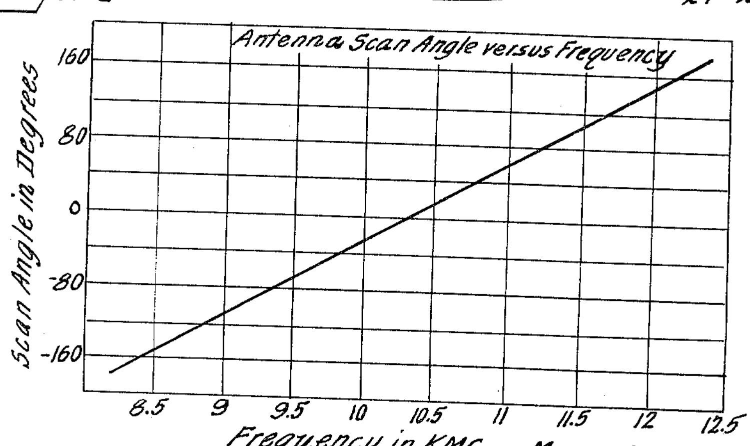


FIG-7-



INVENTOR

Maurice E. Ringenbach,

BY Alfred B. Levine
Seymour M. Rosenberg
Robert H. Lentz ATTORNEYS

Oct. 19, 1965 M. E. RINGENBACH 3,213,454

FREQUENCY SCANNED ANTENNA ARRAY

Filed March 21, 1960

4 Sheets-Sheet 3

FIG. 8

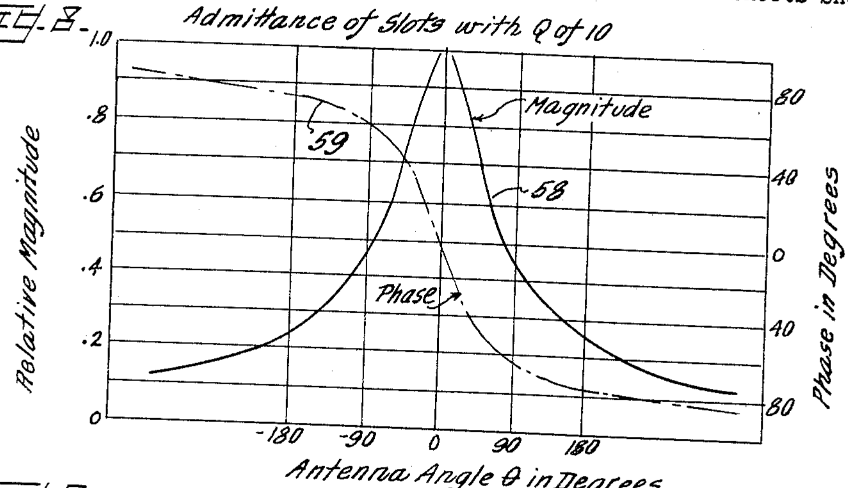


FIG. 9

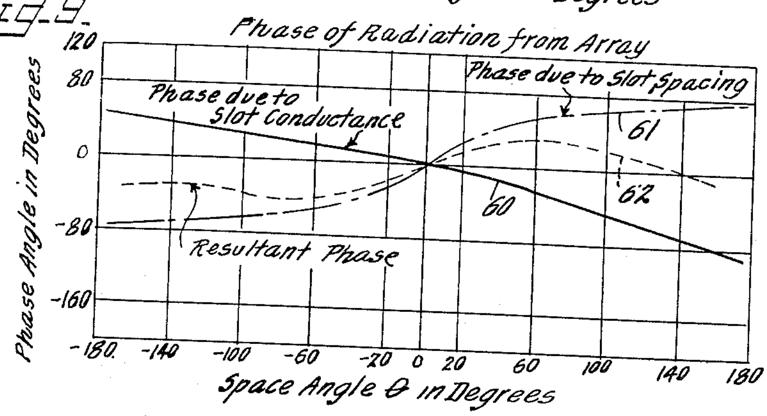
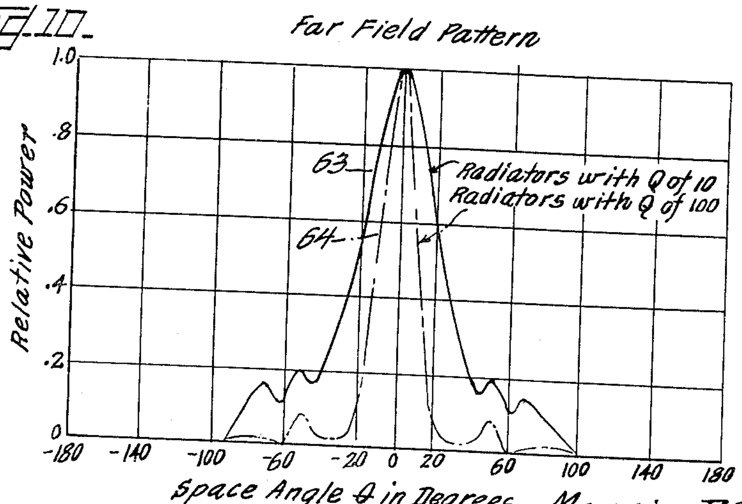


FIG. 10



INVENTOR

Maurice E. Ringenbach,

BY Alfred B. Levine
Seymour M. Rosenberg
Robert H. Lentz

ATTORNEYS

FIG. 11.

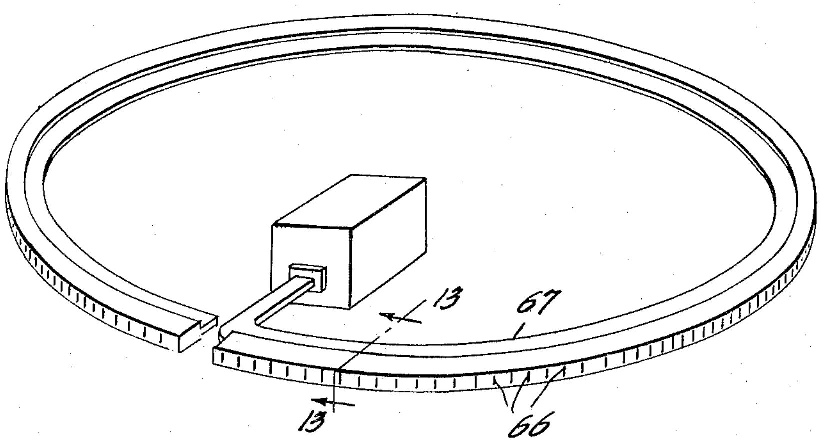


FIG. 12.

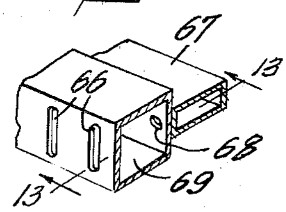


FIG. 14.

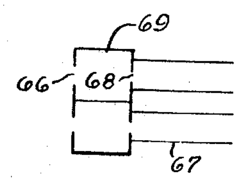
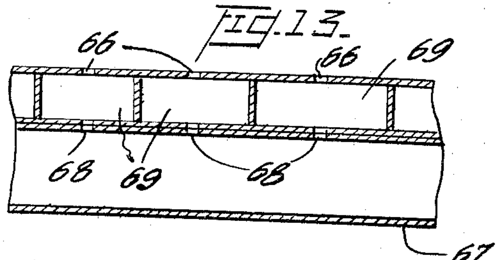


FIG. 13.



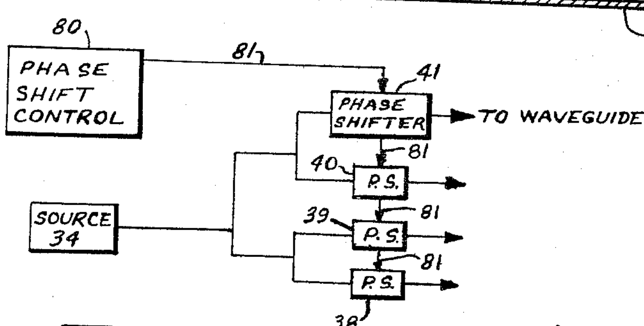


FIG. 15

INVENTOR

Maurice E. Ringenbach,

BY Alfred S. Levine

Seymour M. Rosenberg

Robert H. Lentz

ATTORNEYS

United States Patent Office

3,213,454

Patented Oct. 19, 1965

3,213,454

FREQUENCY SCANNED ANTENNA ARRAY

Maurice E. Ringenbach, Adelphi, Md., assignor, by mesne assignments, to Litton Industries of Maryland, Incorporated, College Park, Md., a corporation of Maryland

Filed Mar. 21, 1960, Ser. No. 16,601
17 Claims. (Cl. 343—754)

This invention relates generally to improvements in electronically controlled scanning antennae and more particularly to such antennae capable of scanning over spatial angles extending to 360°.

The invention can be more clearly comprehended in its most elementary form as comprising a plurality of radiating elements spaced along an elongated straight or arcuate path and commonly fed by a source of high frequency energy. Each of the elements is constructed to possess a different resonant frequency at which that element most efficiently radiates the energy into space or receives energy, and the individual elements in this array are positioned in such order as to progressively resonate in sequence from one end of the path to the other as the frequency of the power source is varied. Consequently, as the source of frequency is varied, the radiated beam is effectively physically displaced along the elongated path to scan wide spaced angles in space and, in the event that the antenna elements are arranged in a circular path, the beam is progressively displaced outwardly from a circle to scan spatial arcs extending to 360° if desired.

This construction and mode of operation is to be particularly contrasted with those known types of scanning array systems employing a plurality of spaced radiating elements in which a limited angular displacement of the beam for scanning purposes is obtained by varying the electrical phasing of the energy to the various elements. In this latter type of scanning antenna system or array, the beam is not physically displaced along the array as in the present invention, but rather its spatial angle referenced to the array is varied by adjusting the relative phase between the elements.

Stating this difference in another manner, the known scanning antennae of the phase displacement variety are adapted to function at a fixed frequency or within a narrow band of frequencies and any variation in the energizing frequency outside this narrow band not only distorts the radiated beam but considerably reduces the radiated power. According to the present invention on the other hand, the individual radiating elements in the array are each constructed to radiate at different frequencies and the wide range scanning action desired is obtained by locating the radiating elements so that each observes a different area in space as it radiates.

According to one preferred embodiment of the invention, the individual radiating elements, and the means for commonly feeding these elements with power, is conveniently in the form of a waveguide having spaced slots therein along its length, each slot serving as an individual radiating element. To render each such radiating element responsive to a different frequency, the slot lengths are all different and are chosen to progressively increase or decrease in size in a predetermined manner along the length of the waveguide, and the spacing between the slots is also varied to compensate for the difference in wavelength between slots. Since each radiating element has a different resonant frequency by virtue of its unique length, only one slot radiates most efficiently at any one frequency although a number of slots on either side of the resonant slot also radiate but to a lesser degree than the resonant slot. The number of slots radiating on either side of the resonant slot and the degree of radia-

tion from these slots is a function of the "Q" or figure of merit of the slots. The beam is radiated in approximately the direction of the resonant slot and the characteristics of the radiated beam are determined by the shape of the waveguide path, and the "Q" or figure of merit of the slots. Consequently, as the frequency of the source is varied the beam of radiated energy produced is scanned along the length and in the plane of the waveguide.

Among the other features of the invention, there is provided a multiple array of such antennae for enabling a desired shaping of the radiated beam. Additionally, there is provided an arrangement for electronically controlling the scanning of the beam in two orthogonally arranged planes, such as in azimuth and elevation, together with means for controlling this two-plane scanning action either in synchronism or other, as is desired.

To provide a rather unique form of spatial spot scanning, the invention also includes as a feature the incorporation of a lens system in unique combination with a preferred antenna construction whereby the beam may be concentrated in a spot or pencil-like shape and the pencil beam directed to scan separated areas in space as the frequency of the energizing source is varied.

It is, accordingly, a principal object of the invention to provide a wide angle electronically controlled scanning antenna.

A further object is to provide such an antenna whose scanning action is controlled by varying the frequency of the energizing source.

Another object is to provide such an antenna with either a vertically or horizontally polarized beam as is desired.

Still another object is to provide such a scanning antenna having a predetermined beam shape.

A still further object is to provide a scanning antenna capable of simultaneously or sequentially scanning both azimuth and elevation planes responsively to changes in frequency and voltage.

Another object is to provide a scanning antenna capable of simultaneously scanning separated spatial areas simultaneously.

Other objects and many additional advantages will be more readily understood by those skilled in the art after a detailed consideration of the following specification taken with the accompanying drawing wherein:

FIG. 1 is a perspective view illustrating one preferred waveguide embodiment according to the present invention;

FIG. 2 is an enlarged view of a section of the antenna of FIG. 1;

FIG. 3 is a view similar to FIG. 2 illustrating a modified slot construction;

FIG. 4 is a perspective view of a stacked array of the antennae of FIG. 1 for beam shaping purposes;

FIG. 5 is a view similar to FIG. 4 and illustrating means for providing scanning in two orthogonal planes;

FIG. 6 is a perspective view illustrating the use of a dielectric lens for focusing the scanable beam;

FIGS. 7 to 10 are plotted charts illustrating various characteristics of the antenna structure; and

FIGS. 11 to 13 are perspective and sectional views illustrating further modifications to the antenna of FIG. 1.

FIG. 14 illustrates in cross-section the stacking of the waveguides of FIG. 13; and

FIG. 15 is a diagrammatic showing of the interconnection of the phase shifters in FIG. 5.

Referring now to the drawings for a detailed consideration of the invention, there is shown in FIG. 1 a preferred antenna structure for scanning over 360° or any angular sector within this total angle. As shown, the antenna comprises a horizontal waveguide **10** of rectangular cross-section having spaced slots **11**, **12**, **13**, . . . formed in the narrow or side wall thereof. The waveguide **10** is formed in a circular configuration to extend over substantially 360° in space with the slots therein being spaced along the outer wall whereby each slot observes outwardly at a different azimuth angle around the circle.

As best shown in FIG. 2, illustrating in enlarged scale a short portion of the waveguide **10** of FIG. 1, each of slots **11**, **12**, and **13** is of different size than the others; with the various slots being progressively greater in length along the waveguide. As will be more fully discussed hereafter, the resonant frequency of each slot is primarily determined by the length of its aperture, whereby each slot is constructed to most efficiently radiate energy at a different frequency, and the slots along the waveguide are, accordingly, adapted to progressively resonate in sequence as the frequency is varied.

As shown, the waveguide **10** is driven by a variable frequency oscillator **14**, which may be of the voltage tunable variety, or other variable types, that are well known. As the frequency of oscillator **14** is varied, the beam is continuously radiated outwardly from different positions along the length of the waveguide; or in other words, the beam is physically radiated from position to position along the waveguide **10** whereby, if the waveguide **10** is in circular form as in FIG. 1, the beam, in moving about the circle, scans over a full 360° in azimuth, or any portion thereof.

The pattern of the beam emanating from the slots **11**, **12**, **13**, etc., is substantially in fan-shape that is relatively narrow in azimuth (plane of the ring **10**) but wide in elevation to provide a horizontally polarized pattern. If it is desired to provide a vertically polarized pattern, the waveguide antenna and slots therein may be formed as shown in FIG. 3, with the waveguide **15** being bent in the E-plane and the slots, such as **16** and **17** being horizontally arranged and staggered in the broad wall of the waveguide. The dimensions of slots **16** and **17**, in FIG. 3, are progressively varied in size in the same manner as in FIG. 2 to render each slot resonant at a different frequency. The reason for alternately inclining the slots, as in FIG. 2, is to excite the slots in such manner as to cancel the unwanted polarization. The slots shown in FIG. 3 are staggered in order to excite adjacent slots in phase.

To maintain the pattern of the radiated beam substantially constant during scanning, as the beam is emanated from different positions along the length of the waveguide, the physical spacing between the individual slots is also graduated. For example, it is usually desirable to space the slots in a waveguide antenna about one-half waveguide wavelength apart, and in any event less than one full wavelength apart. According to the present invention, the slots are each spaced from the next by one-half waveguide wavelength at their resonant frequencies whereby the slots that are adapted to resonate at the lower frequencies are spaced further apart corresponding to one-half wavelength at their respective lower frequencies and those resonating at the high frequencies are likewise spaced progressively closer together, corresponding in each case to one-half waveguide wavelength at their resonant frequency. Consequently, as the frequency is varied and the antenna scans different spatial areas as the beam is displaced along the waveguide length, the phase of the energy exciting the resonant and near resonant slots is preserved and the beam remains substantially unchanged electrically at each position along the waveguide.

FIG. 4 shows an alternative embodiment of the invention for the purpose of shaping the beam in a second or elevation plane. In this arrangement, a plurality of ring-shaped waveguide antennae **18** to **24**, each being at the type shown in FIGS. 1 and 2, are stacked one above the other in coaxial alignment. All of the waveguide antennae **18** to **24** are adapted to be simultaneously energized, each being fed by a directional coupler, coupled to a central

feed waveguide **25**, arranged in sinuous form as shown, which central feed waveguide **25** is, in turn, coupled to receive energy from a variable frequency oscillator **26**. All of the waveguides **18** to **24** are also positioned with their correspondingly sized and shaped slot openings in linear vertical alignment. Consequently, with this arrangement, a different vertical line of slots resonates at each different frequency to produce a shaped pattern in elevation likened to a vertical array of separate antennae. The particular elevation pattern obtained depends upon the number of waveguides employed and the relative phase and amplitude between the slots in the vertical plane.

For example, a stacked array employing seven such waveguides spaced about one-half wavelentgh apart and fed to achieve a −20 db side-lobe level will produce a half-power beamwidth of about 16.4°. A cosecant squared pattern having a 14.5° half-power beamwidth in the elevation plane can also be obtained from seven such waveguide rings spaced about three-quarters (¾) wavelength apart.

Consequently, by stacking the antennae as in FIG. 4, a fan-shaped beam that is relatively narrow in azimuth and variably shaped in elevation may be obtained, and this shaped beam may be displaced or translated from position to position about the stacked waveguide rings in the same manner as in FIG. 1 with variation in the frequency of source **26**, thereby to scan wide arcs in space extending to 360°, if desired.

FIG. 5 illustrates a further modification of the invention to provide either scanning of the beam in elevation or controllable positioning of the beam in the elevation plane. In this arrangement a plurality of such waveguide rings **27** to **33** are stacked in vertical coaxial alignment, as in FIG. 4, and all are adapted to be energized in common by a variable frequency energizing source **34**. To provide for scanning of the beam in the elevation plane, there is provided phase shifters **35** to **41**, respectively, near the entrance to each waveguide ring to vary the phase of the signal entering the waveguide with respect to the others. By changing the relative phases of the signals in the different waveguides, the radiated beam may be angularly displaced in the elevation plane and by continuously varying the phase shifters to progressively vary the phase shift of the signals entering the waveguides, the beam is progressively scanned along an arc in the elevation plane.

More specifically, if the phase shifters provide a constant phase shift the signal fed to each waveguide is in fixed phase relation with the others and the beam observes a fixed elevation area in space. However, if the phase shifters are made variable and are properly varied, the position of the beam in elevation is also varied whereby the beam is made to scan an arc in elevation. By continuously varying the phase shifters in synchronism with change in frequency of oscillator **34**, the beam is made to continuously scan in both the azimuth and elevation planes thereby providing accurate surveillance over a wide cylindrical area in space outwardly from the stacked antenna rings.

To provide electronic scanning of the beam in elevation, it is preferred to employ electronically controllable phase shifters **35** to **41** that are adapted to vary phase shift over a wide range with change of an energizing current. Among the known devices of this type are the ferromagnetic phase shifters. Known devices of this type, however, also provide an insertion loss or attenuation of the signal. Consequently, to insure that the signal is equally attenuated in each waveguide, the waveguide rings **27** to **33** are preferably fed in parallel, with the signal from oscillator **34** being introduced through a branching waveguide feed network shown at **42** in FIG. 5 that provides the desired parallel feed through equal length waveguide sections to each antenna ring.

As is well known, the phase shift provided by known phase shifters of this type also varies with frequency and consequently if a constant elevation scanning angle is desired during variation of the frequency for scanning in azimuth, it is necessary to compensate for the variation in phase. This may be accomplished by programming the phase shifter with a changing current to vary the shift thereof equally and opposite to the error caused by variation in the frequency of oscillator **34**.

As thus far described, therefore, FIG. 5 illustrates an antenna construction according to the present invention wherein a focused beam that is narrow in azimuth and shaped in elevation may be electronically scanned over wide arcs in the azimuth plane extending to 360° and also scanned over wide arcs in the elevation plane. The azimuth scanning is obtained by varying the frequency of the oscillator **34** which results in the circularly disposed radiator elements successively resonating, and the scanning action in the elevation plane is obtained by varying ferrite phase shifters and, therefore, the relative phase shift of the signal energizing the different vertically stacked antennae. Each of these controls may be exercised independently of the other or simultaneously with the other whereby the antenna array may scan over wide elevation arcs at any given azimuth position or over wide azimuth arcs at a desired elevation position, or made to simultaneously scan in azimuth and elevation.

FIG. 6 illustrates an additional variation of the invention to enable spot-like scanning of spaced areas in space by employing a dielectric lens. In this arrangement a single antenna ring **53** is employed having its radiator slots disposed in the inside narrow wall of the ring. Concentrically positioned within this ring antenna **53** is a spherically-shaped dielectric lens **55**, of the Luneberg variety, whose dielectric constant is made variable being maximum at the center of the sphere and becoming progressively lower toward the outside surface thereof. The lens **55** focuses this energy, thereby increasing the gain of a single waveguide ring **53**. As the frequency of the signal energizing the waveguide **53** is varied, its radiated beam is displaced about the equator of the spherical lens **55** whereby a pencil-like beam, being radiated outwardly into space, is transferred from position to position to scan around a circular path.

For a more comprehensive understanding of the construction and mode of functioning of the invention, reference is now made to FIGS. 7 to 10 illustrating the characteristics of an antenna constructed as in FIG. 1 to scan over arcs to and including 360° in the azimuth plane. The characteristics plotted are for a circularly arranged waveguide antenna having a diameter of about 25 wavelengths at midband and being provided with about 130 slots in the narrow wall thereof that are variably spaced apart and dimensioned to linearly scan over a 360° arc in azimuth by varying the frequency over a range of from 8.2 kilomegacycles to 12.4 kilomegacycles as shown in FIG. 7.

Since the antenna beam shape is a function of the combined amplitude and the phase of the energy radiated from the individual slots, it is first necessary to consider the radiating characteristics of each slot. According to the present invention it has been found that each slot behaves in the manner of a series resonant circuit having reactance and resistance. Consequently, at the frequency of resonance, the magnitude of the energy radiated from each slot is at a peak or maximum as indicated by curve **58** in FIG. 8 and the phase angle of the radiated signal therefrom is zero as shown by curve **59**. The adjacent slots on either side of the resonating slot are not in a resonance condition at that frequency and consequently radiate less energy and not in phase with the resonant slot. For example, as shown in FIG. 8, the slots that are displaced ninety degrees apart from the resonating slot around the antenna ring radiate a considerably lower amplitude signal than that being radiated by the resonant slot and in an out-of-phase relationship therewith.

The phase of the radiated energy from any given slot is determined by two factors, the phase due to the argument of the slot admittance and the phase resulting from slot spacings that differ from one-half wavelength. Although the slots closely adjoining the resonant slot are spaced approximately one-half wavelength apart, the slots adapted to resonate at lower frequencies are spaced further apart corresponding to one-half wavelength at the lower frequency and those designed to resonate at higher frequencies are positioned closer together.

Referring to FIG. 9 it is noted that the phase shift due to slot conductance (curve **60**) varies from a displacement of about 40 degrees at a position on the antenna ring of −160° in azimuth to a phase displacement of −40° at an azimuth position on the antenna ring of 160°. The variation in phase, due to the unequal slot spacing (curve **61**) on the other hand, varies in the opposite direction ranging from about −80° to +80° for the same angular displacement over the antenna ring. The resulting phase of the radiated signal (curve **62**), therefore, lies in between the two phase components.

FIG. 10 illustrates the far field patterns being generated by this antenna construction for a Q of 10 and for a Q of 100. The pattern obtained from an array of slots having a Q of 10 (curve **63**) has a half-power beamwidth of about 44° and the first side lobes are down 7 db. The radiation pattern from an array of slots having a Q of 100 (curve **64**) has a half-power beamwidth of 22° and the first side lobes are down −11 db.

One manner of varying the antenna ring construction to obtain slot radiators having a Q of 100 or greater, is illustrated in FIG. 11 and in the enlarged views thereof, as shown in FIGS. 12 and 13. In this modification the slot radiators **66** are not formed directly in the arcuately curved waveguide **67**, but rather the outer wall of the waveguide **67** is provided with a plurality of spaced coupling holes **68** each leading to a separate small cavity resonator **69**. The energy being fed from the waveguide is, therefore, introduced into the cavity resonators **69** through the openings **68** in the waveguide wall and in turn radiated through the slot **66** formed in the opposite wall of each cavity resonator. Naturally as the Q of the slots is made greater, the antenna beamwidth is decreased.

Although preferred embodiments of the invention have been described and illustrated as embodying slotted waveguide construction, it is believed evident to those skilled in the art that transmission lines, other than waveguides and radiating elements, other than slots, may be employed without departing from the spirit and scope of the invention. Additionally, since the antenna structures, as described, function reciprocally, it is also considered evident that the antenna functions in the same manner for reception as well as transmission. Since these and many other variations are considered within the realm of those skilled in the art without departing from the teaching of the present invention, this invention should be considered as being limited only according to the following claims.

What is claimed is:

1. A scanning waveguide antenna having a plurality of slotted openings therein spaced along its length, said openings at different locations along the waveguide being of different dimensions to resonate at a different frequency with the variously sized slots arranged in order of increasing size thereby to progressively resonate as the frequency is varied, said slotted openings of different dimensions being unequally spaced apart each from the next by a spacing corresponding to less than one waveguide wavelength of a different frequency, whereby in response to each of different frequencies energizing said waveguide only those slots having dimensions that are resonant at that frequency will resonate and radiate energy substantially in phase relation with said energization and said remaining slots are rendered both non-resonant and in out-of-phase relationship therewith, said waveguide being shaped along its length in a circular configuration thereby

to enable scanning over an arc extending to 360°, said slots being positioned to provide a horizontally polarized beam; a plurality of said waveguides in cascaded coaxial relation and each adapted to be energized by the same source of energy, thereby to shape the radiated pattern in two orthogonal planes.

2. In the antenna system of claim 1, a variable phase shifter intermediate each pair of adjoining waveguides, thereby enabling scanning in both orthogonal planes.

3. In the system of claim 2, said phase shifters being energizable to vary the degree of phase shift thereby to variably control the pattern in one plane.

4. A multiple array electronic scanning antenna system comprising: a plurality of separate waveguides each formed in a circular configuration along their length, said waveguides being positioned in cascaded coaxial relation, coupling means for enabling energization of all waveguides by a common source of energy, each of said waveguides having slotted openings of different dimensions disposed along its length with said openings being unequally spaced apart, whereby different openings in each waveguide are adapted to resonate at different frequencies of the energizing source, thereby to provide a displaceable array of radiating elements at each different frequency of said source.

5. In the antenna system of claim 4, means for decreasing the resonant bandwidth of said openings in said waveguides, said means comprising a plurality of resonant cavities included with each waveguide, each cavity coupling the interior of the waveguide through an opening in the waveguide.

6. A scanning waveguide antenna having a plurality of slotted openings therein spaced along its length, said openings at different locations along the waveguide being of different dimensions to resonate at a different frequency and with the variously sized slots being arranged in order of increasing size thereby to progressively resonate as the frequency is varied, said slotted openings of different dimensions being unequally spaced apart each from the next by a spacing corresponding to less than one waveguide wavelength of a different frequency and means for applying energy to said waveguide to excite all of said slots, whereby in response to each of different frequencies energizing said waveguide only those slots having dimensions that are resonant at that frequency will resonate and radiate energy substantially in phase relation with said energization and said remaining slots are rendered both non-resonant and in out-of-phase relationship therewith, and means incorporated within said waveguide for decreasing the resonant bandwidth of said slots.

7. A scanning waveguide antenna comprising an elongated waveguide of uniform cross section along its length, said waveguide having a plurality of openings therein spaced along its length, said openings at different locations along the waveguide being of progressively different dimensions to resonate at different frequencies, said different openings being unequally spaced apart, each from the next, by a spacing coresponding to less than one wavelength of a different frequency, whereby in response to different frequencies energizing the waveguide all said openings are excited but only those openings having dimensions that are resonant at each different frequency will radiate energy substantially in phase and said remaining openings are rendered both non-resonant and in an out-of-phase relationship therewith.

8. A plurality of antennas of claim 7, and coupling means including phase shifting means for commonly energizing said waveguides by a common source.

9. In the antennas of claim 8, said phase shifters being adjustable to vary the relative phase relationship of the energization to said waveguides.

10. A scanning waveguide antenna having a plurality of slotted openings therein spaced along its length, said openings at different locations along the waveguide being of different dimensions to resonate at a different frequency

with the variously sized slots arranged in order of increasing size thereby to progressively resonate as the frequency is varied, said slotted openings of different dimensions being unequally spaced apart each from the next by a spacing corresponding to less than one waveguide wavelength of a different frequency, whereby in response to each of different frequencies energizing said waveguide only those slots having dimensions that are resonant at that frequency will resonate and radiate energy substantially in phase relation with said energization and said remaining slots are rendered both non-resonant and in out-of-phase relationship therewith, said waveguide being shaped along its length in a circular configuration thereby to enable scanning over an arc extending to 360°, said slots being positioned to provide a horizontally polarized beam, said antenna having the openings about the inside diameter wall of the waveguide, and a spherical dielectric lens positioned concentrically within the curved waveguide and girdled thereby.

11. In an electronically scannable multiple antenna array system, a plurality of elongated energy transmission members positioned in a cascaded array, each of said members being provided with a plurality of radiating means spaced along its length and with each of said means being resonant at a different frequency, and means coupling all of said energy transmission members for common energization by a variable frequency source whereby as the frequency of the source is varied different radiating means on each of said transmission members resonates to provide a different array of resonant means at each different frequency, phase shifting means coupling each of said members to said variable frequency energizing source, said phase shifting means being variable, thereby enabling scanning of said radiated beam in one plane at each position along said energy transmission members with variation of the phase shifters, and scanning movement of the radiated beam in a second orthogonal plane along the length of the members with variation in frequency of the energizing source, and means for varying said phase shifters and said frequency source together thereby to provide simultaneous scanning in two orthogonal planes.

12. An electronically scannable antenna comprising a waveguide formed in an arcuate configuration along its length and having inner and outer side walls, said waveguide having a plurality of slots of different size and variable spacing therebetween provided in one side wall of the waveguide, and beam focusing means for said antenna comprising a dielectric lens member having a shaped arcuate surface compatibly shaped with the wall of the waveguide having the slots therein, said waveguide being formed in an arc of substantially 360°, and said lens comprising a spherically shaped member girdled by said transmission member and having a dielectric constant progressively changing from its surface to its center.

13. In an electronically scannable multiple antenna array system, a plurality of elongated energy transmission members, each of said members being provided with a plurality of radiating means spaced along its length and with each of said means being resonant at a different frequency, said elongated transmission members being so arranged that different ones of the radiating means of each transmission member forms an array with corresponding different radiating means of the other transmission members, thereby to form a plurality of arrays spaced apart from one another, and with the resonant frequency of the radiating means in each array being the same but different from the resonant frequency of the other arrays, and means coupling all of said energy transmission members for common energization by a variable frequency source whereby as the frequency of the source is varied, a different array of radiating means resonates at each different frequency, said coupling means including phase shifting means for each of said transmission members for coupling that energy transmission member to be energized by a common energy source, whereby variation of

said phase shifting means provides a series of antenna beams having different locations and scanning directions for each different frequency of said energy source.

14. A scanning waveguide antenna having a plurality of slotted openings therein spaced along its length, said openings at different locations along the waveguide being of different dimensions to resonate at a different frequency with the variously sized slots arranged in order of increasing size thereby to progressively resonate as the frequency is varied, said slotted openings of different dimensions being unequally spaced apart each from the next by a spacing corresponding to less than one waveguide wavelength of a different frequency, whereby in response to each of different frequencies energizing said waveguide only those slots having dimensions that are resonant at that frequency will resonate and radiate energy substantially in phase relation with said energization and said remaining slots are rendered both non-resonant and in out-of-phase relationship therewith, means included with each waveguide for decreasing the resonant bandwidth of the slotted openings in the waveguide, said means comprising a plurality of resonant cavities, each cavity coupling the interior of the waveguide to a different one of said slotted openings.

15. In an electronically scannable multiple antenna array system, a plurality of elongated energy transmission members, each of said members being provided with a plurality of radiating means spaced along its length and with each of said means being resonant at a different frequency, said elongated transmission members being so arranged that different ones of the radiating means of each transmission member forms an array with corresponding different radiating means of the other transmission members, thereby to form a plurality of arrays spaced apart from one another, and with the resonant frequency of the radiating means in each array being the same but different from the resonant frequencies of the other arrays, and means coupling all of said energy transmission members for common energization by a variable frequency source whereby as the frequency is varied a different array of radiating means resonates at each different frequency, phase shifting means coupling each of said members to said variable frequency energizing source, thereby to provide an antenna beam having a given pattern and direction.

16. In the antenna of claim 15, said phase shifting means being variable, thereby enabling scanning of said radiated beam in one plane at each position along said energy transmission member with variation of the phase shifters, and scanning movement of the radiated beam in a second orthogonal plane along the length of the member with variation in frequency of the energizing source.

17. In an electronically scannable mattress array antenna system, a plurality of waveguides positioned in side-by-side array, each of said waveguides having openings of different dimensions disposed along its length with said openings being unequally spaced apart, whereby different openings in each waveguide are adapted to resonate at different frequencies of the energizing source, means coupling all of said waveguides for common energization by a variable frequency source whereby as the frequency of the source is varied, different radiating means on each of said transmission members resonates to provide a different array of resonant means at each different frequency, said coupling means including adjustable phase shifters whereby adjustment of the phase shifters shifts the scanning direction of the resonant means.

References Cited by the Examiner

UNITED STATES PATENTS

2,407,169	9/46	Loughren	343—854 X
2,464,276	3/49	Varian	343—768
2,523,455	9/50	Stewart	343—771
2,676,257	4/54	Hebenstreit	343—771
2,881,431	4/59	Hennessey	343—753
3,083,360	3/63	Welty et al.	343—854

FOREIGN PATENTS

983,033 2/51 France.

OTHER REFERENCES

Pub. II, Eaton: "An Extension of the Luneberg-Type Lenses," NRL Report 4110, Feb. 16, 1953.

Pub. I, Kraus: "Antenna," McGraw-Hill Book Co., New York, 1950 (pages 356–358 relied on).

ELI LIEBERMAN, *Primary Examiner.*

JOHN W. HUCKERT, GEORGE N. WESTBY, HERMAN KARL SAALBACH, *Examiners.*